FLUORINE-PHOSPHATE RATIOS IN RELATION TO THE AGE OF THE KEILOR SKULL, A TERTIARY MARSUPIAL, AND OTHER FOSSILS FROM WESTERN VICTORIA

By Edmund D. Gill, B.A., B.D., F.G.S., Curator of Fossils, National Museum of Victoria.

Summary

Fluorine analyses indicate the relative ages of fossil bones from sites in Central and Western Victoria. They show that the Keilor Skull is a true fossil and not a recent burial; also that a fossil kangaroo jaw from near Hamilton does belong to the Lower Pliocene marine bed whence it was extracted. A Tertiary cuscus tooth from the same area is recorded. Causes of variation in fluorine index are discussed.

The Fluorine Index

Every ton of the earth's crust averages something like 300 grams of fluorine (Mason 1952), and for any given groundwater environment with fluorine in solution, the accumulation of fluorine ions by fossil bones, if pervious, is a function of time. Thus bone fossils of the same age and in the same geological formation will possess comparable amounts of fluorine, and be distinguishable from any bones in that formation introduced somewhat later by natural or human burial, insertion down joint planes, cracks, caverns, animal and bird burrows, and such like. Rock matrices of fossil bones vary both in permeability (contrast clays and gravels) and fluorine content, and so different geological formations may possess differing ground waters in respect both to circulation and fluorine content.

The hydroxylapatite of bone possesses a molecular structure with a high affinity for fluorine ions, and so if any of the latter are available, they are readily assimilated, thus forming the stable compound fluorapatite. Recognizing that varying amounts of secondary minerals in fossil bones could vitiate a figure giving simply the percentage by weight of fluorine, Oakley and Hoskins (1950) have related this figure to the percentage by weight of phosphorus (as P_2O_5) with which the fluorine is chemically associated. The result is presented by a figure calculated thus:—

$$\frac{\%\ \text{Fluorine} \times 100}{\%\ P_2O_5}$$

It is suggested that this figure be known as the *Fluorine Index.*

After analyzing hundreds of fossil bones and experimenting with radioactive tracers, Cook (1951) came to the conclusion that "the diffusible anions, phosphate and carbonate, can enter or leave dead or fossil bone with very great facility. It is further probable that such movement is based upon an interchange of ions between the bone substance and the external solution rather than upon a unidirectional accumulation or depletion of a single ion species. Fossil bone, therefore, behaves in a manner fundamentally similar to living bone." Cook considered fluorine a probable exception, and later successfully used the fluorine method himself (Heizer and Cook 1952). While the free movement of ions in and out of a fossil bone renders it useless for absolute age determination by radiocarbon or other isotope method, it does not affect the validity of the relative age determination by means of the fluorine index.

Variation in Fluorine Index

While in most cases satisfactorily fulfilling their purpose of indicating relative ages, the analyses of fossil bones have revealed considerable variation in the fluorine index for bones which one has reason to think are contemporaneous, and have remained in the one site since interment. The full reasons for such variation have yet to be determined, but the following are suggested as factors:—

1. *Variation in the fluorine content of living bone.* Cook (1951) says living bone acts like fossil bone as far as ionic exchange is concerned. Therefore it is to be anticipated that in a fluorine rich area a person or animal would ingest comparatively large amounts of fluorine which would be trapped in the bones and accumulated in the same way as it is in fossil bones. Conversely, in a fluorine deficient area, a person or animal would be expected to have fluorine deficient bones. Evidence for this is found in the fluorine deficiency and fluorine excess (fluorosis) of teeth occurring in various areas. Brekhus and Armstrong (1935, quoted in Marston 1950) state that the mean fluorine content of human tooth enamel is 0.0111 per cent. and that of dentine 0.0169 per cent., while the pooled dentine of a patient with fluorosis showed 0.0504 per cent. fluorine. Mason (1952) states fluorine to be <0.05 per cent. of the body weight of organisms (p. 197). Olsen (1950) gives the percentage of fluorine in the Recent horse of Florida as 0.01. Oakley and Hoskins (1950) reported a fragment of fresh bone from the soil as having

<0.1 per cent. fluorine. Heizer and Cook (1952) record fossil human bones as having 0.01 per cent. fluorine, and Stewart (1952) a fossil bone with only 0.0071 per cent. fluorine. Non-fossil bone analyzed in the present series had 0.002 per cent. to 0.11 per cent. fluorine. From the information available it appears that:—

(*a*) There is considerable variation in the percentage of fluorine in living bone, and more information is needed about this.

(*b*) Theoretically, this could account in certain circumstances for considerable variation in the fluorine index of fossil bones from the same site and of the same age. For example, if a human or animal hunter caught some prey from the presumably fluorine-poor aeolianite of the coast, and some from the fluorine-rich basaltic tuff country nearby, and left bones from each in the same midden or the same lair, a great length of time would need to elapse before the initial difference in fluorine content became insignificant relative to the total quantity of fluorine in those bones. Also a fluorine-rich bone could be intruded thousands of years later into a deposit containing bones that were initially fluorine-poor, and yet have the same amount of fluorine as the older bones. When migrations of birds and animals are contemplated, it is conceivable that bones with very different initial fluorine content could be buried together. In most cases, one assumes, this kind of thing would not happen, but it seems reasonable to expect that the difference in the initial amount of fluorine in bones is one of the causes of variation in the F. index of bones known to be contemporaneous.

The present series of analyses suggests that there is not only difference in fluorine content from animal to animal according to their habitat, but also from part to part of the skeleton of the same animal. The differing fluorine indices of the jaw of the extant *Wallabia* (specimen 12) were obtained from different parts of the same bone, while in the case of the *Rattus* from the Keilor Skull site (specimen 23) the indices were from different groups of bones from the same skeleton. The differences are greater than the estimated range of experimental error, and it appears that the fluorine content varies in different parts of the same skeleton, as some other substances are known to do.* Brekhus and Armstrong (1935) found differences between the dentine and enamel of the same teeth.

A series of analyses has been completed of the same part of the same bone of possums (non-fossil) of the same species (*Trichosurus vulpecula*) from widely separated parts of Victoria and Northern Tasmania (specimens 1 to 8). The results may be compared with those of bonedusts in three areas of Victoria (specimens 9 to 11). No correlation was found between the fluorine content of specimens 1 to 11 and the fluorine content of domestic water supplies in the four areas for which figures were available.

Another point worthy of investigation is whether the bones of marine animals possess more fluorine than the bones of terrestrial animals. And what of predatory animals, either terrestrial or marine, that ingest the bones of other animals? Do they thereby obtain an increased amount of fluorine? Do humans fond of sardines and soused fish, thereby ingesting the bones of marine animals, thus gain significant amounts of fluorine not gained by others?

2. *Variation in the fluorine environment of the fossil bone.* In any given homogeneous rock mass there is presumably little variation in the dissolved mineral content of the percolating waters. The position of a fossil bone relative to the water-table, however, may be important. A bone low in the formation might be bathed without interruption in a mineralizing solution, whereas one high in the same formation might be above the water-table and dry during the summer, or during comparatively arid periods. This is a possible source of variation in the fluorine content of fossil bones. The Keilor Terrace, whence came specimens 18 to 23, is of a porous silt standing high above the river. To the writer's knowledge, the skull site is never reached by the water-table and the ground is only saturated when heavy and continual rain falls. In the Arid Period it would receive still less water.

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* Since writing this paper, the work of J. M. Harvey (1952) on fluorosis of sheep in Queensland has come to my notice. Harvey has shown that in respect to certain experimental sheep—

1. The concentration of fluorine in bones and teeth is not proportional to fluorine intake.
2. In the bones examined, the fluorine storage is greatest in the mandible, then in the femur, tibia and metatarsus, in that order.
3. In the permanent incisor teeth, the fluorine storage in general increases from first pair to second pair to third pair.
4. For the premolars and molars, the fluorine content varies with time of eruption, being lowest in the second molar and comparable in the third premolar and third molar.
5. The fluorine concentration is much greater in dentine than enamel.

There is often a considerable difference in the amount of mineralization of contemporaneous fossil bones taken from cave deposits. Owing to the unequal spread of water in a cave, some bones may be heavily mineralized and even cemented into a cave breccia, while other bones may be comparatively fresh. So it may be imagined that different bones in the same cave, although of the same age, and even of the same skeleton, may have differing opportunities of trapping fluorine ions.

3. *Variation in the permeability of the fossil bone.* The figures given by Brekhus and Armstrong (1935), Oakley and Hoskins (1950), and Harvey (1952) for the fluorine content of the enamel and dentine of teeth suggest that the enamel is more resistant to the absorption of fluorine than dentine, presumably because it is less permeable. The more solid a bone becomes, the less permeable it may be. In the extreme case, if a bone is completely silicified, it becomes as impermeable as a quartz nodule.

4. *Variation through experimental error.* Where the same person carries out a series of analyses, setting a standard for the colour change for the end points of titrations, and so on, it would appear that for that series the experimental error should be less than 0.05 per cent. Some writers have given fluorine percentages to four decimal places, but all these cannot be significant. In the present series, the fluorine percentages have been rounded off to the nearest 0.05 per cent., except in the case of specimens 1 to 11 which were analyzed with a view to noting the small variations from place to place.

Victorian Fluorine Analyses

To Mr. W. R. Jewell, Chief Chemist, State Laboratories, Melbourne, and to his staff, the writer is indebted for their interest in this investigation and the analyses listed on page 111.

Where more than one determination was made from one sample, the results were averaged. Relevant data concerning the specimens analyzed are set out below. In no case were teeth used.

GROUP A. *Specimens* 1 *to* 12.—The ramus of a mandible of a young non-fossil *Wallabia* (P. 15761) was used as a control in the first series of fluorine analyses to get some idea how much fluorine living marsupial bone absorbs (specimen 12). The percentage was higher than anticipated, and repetition of the analysis still gave a high result, the reason for which has not yet been discovered. However, the analysis of the *Trichosurus vulpecula* series (specimens 1 to 8) and the commercial bonedusts (specimens 9 to 11) shows that the average percentage of fluorine in living animal bones in Victoria is comparable with that found in other parts of the world.

Specimen.	% F.	% P_2O_5	$\frac{\% F \times 100}{\% P_2O_5}$	Number of Determinations.
Group A.—Living.				
1 to 8 *Trichosurus vulpecula* (Kerr), silver-grey possum.				
1. Healesville, Victoria	0·033	24·9	0·13	1
2. Anakie Ranges, Victoria ..	0·060	26·3	0·23	1
3. Gelantipy, Victoria	0·047	25·4	0·19	1
4. Avoca, Victoria	0·032	25·2	0·13	1
5. Mansfield, Victoria	0·008	25·1	0·03	1
6. Ararat, Victoria	0·035	24·1	0·15	1
7. Flinders Island, Tasmania ..	0·002	..	<0·01	1
8. Wynyard, Tasmania	0·005	25·1	0·02	1
9. Bonedust (commercial), Bendigo ..	0·016	22·6	0·07	1
10. Bonemeal, Wangaratta	0·022	25·4	0·09	1
11. Bonedust, Ballarat	0·017	22·3	0·08	1
12. *Wallabia*	0·05	27·9	0·2	2
	0·10	26·9	0·4	2
Group B.—Warrnambool District.				
13. Tower Hill beach midden ..	0·15	28·2	0·5	2
14. Bushfield Axe site	1·70	28·5	6·0	1
Group C.—Camperdown District.				
15. Lake Bullenmerri	0·25	24·6	1·0	1
16. Lake Colongulac (surface bone) ..	1·85	28·7	6·4	2
17. Lake Colongulac (giant marsupial site)	1·95	24·6	7·9	1
Group D.—Keilor Skull Site.				
18. Keilor Skull (inside)	0·30	14·9	2·0	1
19. Keilor Skull (outside)	0·30	15·3	2·0	1
20. *Macropus* vertebra	0·35	18·8	1·9	1
21. *Vombatus* humerus	0·40	26·7	1·5	1
22. Bone fragment	0·85	29·7	2·9	1
23. *Rattus*	0·75	19·6	3·9	1
	0·50	11·3	4·4	2
Group E.—Hamilton District.				
24. cf. *Macropus*	1·95	24·8	7·9	1
25. Bone from Lower Pliocene marine shell bed	2·75	26·0	10·6	1
26. Bone from underlying nodule bed	3·20	29·7	10·8	1

Late Quaternary Fossils

GROUP B comprises two specimens from the Warrnambool District of Western Victoria associated with the ash spread of Tower Hill, a recent volcano (Gill 1950).

Specimen 13 (P. 15762) is a marsupial bone from the Koroit or Tower Hill beach aboriginal kitchen midden (Gill 1951*a*) dated by radiocarbon analysis as being 538 ± 200 years old (Libby 1951). The midden is on calcareous beach sand just above a buried shore platform of tuff and lapilli from the nearby Tower Hill volcano (Gill 1953*a*). This specimen is included because it ties up the relative dating by fluorine analysis with the absolute dating by radiocarbon analysis, and also because it provides a contrast with specimen 14, which comes from *under* the volcanic ash spread, *over* which is the midden whence came specimen 13.

Specimen 14 (P. 15763) is a macropodid jaw from the Bushfield Axe site (Keble 1947). On the right bank of the Merri River at Bushfield, north of Warrnambool, a farmer sank a hole eight feet deep in the river terrace to anchor a winch. Under hard tuff, in a layer of tuffaceous freshwater limestone, an aboriginal basalt axe with hafting groove was found along with some black shiny mineralized bones. The writer has since examined the site on a number of occasions, finding numerous bones, along with flake and bone implements, in the river deposits nearby (Gill 1953*a*). No outcrop of tuffaceous limestone was found in the tuff cliff of the river, so it may be part of a buried terrace on which there was an aboriginal feasting place. For the fluorine test, one of the bones collected by Keble from the excavation was used, because it came indubitably from under the tuff. Specimen 14 is associated with the same ash spread as specimen 13, but the sites are 7½ miles apart in a direct line, and specimen 13 comes from over the tuff while specimen 14 comes from under it.

The marked increase in the fluorine index of specimen 14 over specimen 13 is paralleled by the increase between specimens 15 and 17 from above and below (respectively) the Hampden Tuff in the Camperdown district. In both cases the degree of increase is greater than anticipated and apparently is due to a rich fluorine environment originating in the apatite of the basaltic tuff. Barth (1947) writes, "In basalts and gabbros fluorine is present as apatite . . . Great amounts of fluorine are exhaled by volcanic eruptions." The permeability of the tuff provides maximum opportunity for the ground water to penetrate and take the fluorine into solution.

GROUP C comprises three specimens from the Camperdown district of Western Victoria associated with the Hampden Tuff formation.

Specimen 15 (P. 15764) is a ramus of the mandible of *Macropus canguru* collected by the writer from the lacustrine terrace deposits surrounding the crater now occupied by the deep Lake Bullenmerri. Thus it is later than the tuff. Some of the bones from the lake have been found *in situ* but most are found on the beaches, sluiced by the lake from the terrace deposits. The bones are somewhat mineralized and generally reddish in colour.

Specimen 17 (P. 15766) comes from a small quarry on the east side of Lake Colongulac (see maps Gill 1951*b*, 1953*a*), whence have come the red, very heavily mineralized bones of extinct giant marsupials. A piece of marsupial bone was used for the fluorine test. A radiocarbon analysis is being made of *Coxiella* shells from the same quarry. The site is also of interest because from this same horizon came a jaw of a dingo, and the carved Colongulac Bone, both presumptive of the presence of man. The formation from which the fossils come is overlain extensively by the Hampden Tuff, but at the site whence came the bone for fluorine analysis, this has been stripped off and replaced by a dune of windblown lake sediment largely derived from the tuff. This material is also presumably rich in fluorine.

Specimen 16 (P. 15765) was included for check purposes. It is a ramus of a mandible of *Macropus canguru* found on the surface at the same site as specimen 17. The bone is heavily mineralized, but whitish and not red like the other bones. It was desired to ascertain whether it is part of the skeleton of a recent *M. canguru* quickly mineralized or a member of the fauna which included the extinct giant marsupials. Its fluorine index leaves no doubt that it belongs with the giant marsupials, and is probably a bone washed out by the lake waters and bleached on the shore. We can therefore conclude that *Macropus canguru*, the Great Grey or Forester kangaroo which is still living in Western Victoria, lived in the Camperdown District as a contemporary of the giant marsupials. The Pleistocene giants have now died out, as in other parts of the world, and indeed this process appears to be still in progress. At the present time the smaller marsupials are the more successful, and there is a tendency for the larger forms to die out. *Macropus canguru* did not exist in very great numbers in the Pleistocene judging by the fossils found, while *Macropus titan* was the dominant kangaroo numerically (Gill 1953*b*). In the Holocene, *M. titan* disappeared, and *M. canguru* became the dominant form in this area.

The Keilor Skull

GROUP D. Fossils are rare in the Keilor Terrace, but the following have been found and used for the fluorine analyses.

Specimen 20 *Macropus* vertebra (P. 15770). At the time the Keilor Skull was found, two vertebrae (P. 15770-1) were obtained, which prove to be of kangaroo. These fossils were collected by the workmen digging out the terrace silt for molding sand, and no accurate information could be obtained of their spatial relationships. Sediment extracted respectively from the spinal canals of these vertebrae, sediment from the Keilor Skull, and sediment from the Keilor Terrace itself were examined by Dr. A. W. Beasley, and found to be similar. "Two sources for the suite of heavy minerals are clearly indicated", the report reads, "one basic and fairly recent, and the other acidic and much earlier. The bulk of the heavy minerals in each sample appears to have come from basaltic rocks." The source of the acid minerals is the granodiorite at Broadmeadows which erosion has recently exhumed. From this granodiorite came largely the sands and gravels underlying the basalt. These, being eroded by the river, constitute second or later cycle materials, more worn than those from the basalt which covers the plain into which the river has cut. The bedrock of Silurian siltstones and sandstones provides a still older source.

Specimen 21 *Vombatus* (P. 15772). Half of a wombat humerus was found in 1951 by Mr. D. J. Tugby, Curator of Anthropology of the National Museum of Victoria. It came from the higher part of the terrace.

Specimen 22 (P. 15776). In January, 1953, Mr. F. S. Colliver observed a small fragment of bone in the Keilor Terrace at the skull site, and this was collected by the author. It came from three feet below the top of the terrace, and 35 yards west of the location of the skull.

Specimen 23 *Rattus* cf. *assimilis* (P. 15773). This fossil was collected by the writer in 1949 about 4 feet below the top of the terrace and 32 yards east of the location of the skull. The bones of the skeleton were together but slightly strung out. The picture given is of a rat washed down the river, then the skeleton disturbed by the accumulation of sediment as the soft parts decomposed. Thus the rat was buried when the sediments of the Keilor Terrace were laid down, and did not die in a burrow subsequently, i.e., it is contemporaneous with the terrace. The fluorine percentage is compatible with that of the other specimens from the same site, but unexpectedly high. The fluorine and phosphate percentages differ markedly for the two samples (different parts of the same skeleton), but the indices calculated from them are comparable. Since rats ingest the bones of other animals, they may gain extra fluorine in that way.

Specimens 18 *and* 19. *The Keilor Skull.* When Mahony reported the Keilor Skull, mention was made of a second skull (1943*b*, p. 31), and a signed statement (which included a reference to the second skull) by the contractor working the quarry was published. It has now been satisfactorily established that there was no second skull. The Chief Commissioner of Police for Victoria, Mr. A. M. Duncan, kindly had the whole matter of these human remains officially investigated. The contractor's statement arose apparently from his lack of knowledge of the bones concerning which he signed, and the statement was not made out by him.

Samples of about a quarter of a gram were used for all the fluorine analyses reported in this paper, except those from the Keilor skull which were as follows:—

Specimen 18. Inside of right petrous temporal . . 0.09 gm.

Specimen 19. Outside of right squamous temporal 0.05 gm.

Keilor Skull is not a Burial

Finding the age of the Keilor Terrace greater than he assumed it to be theoretically, Keble found " reason for believing that the skeleton may have been a burial " (Keble and Macpherson 1946, p. 52). The area has been re-studied geologically, and the age of the terrace can be stated to be less than originally calculated (Gill 1953*c*). A full report is in preparation. From the following evidence it appears certain that the skull was not a burial:—

(*a*) The fluorine analyses show that the skull possesses an F. index comparable with those of fossil *Macropus, Vombatus,* and an indeterminable bone from the same terrace at the same site.

(*b*) The skull was found minus the lower jaw and minus most if not all the rest of the skeleton. Fragments of two femora were found at the time the Keilor Skull was discovered, but although these have been stated to be human, and have been so listed, the anatomists advise me that this has not really been established. Even so, far more complete remains would be expected if this were an aboriginal burial.

(*c*) The Keilor Skull was approximately 9 feet from the surface of the terrace when found, about 25 feet in a direct line from the bank of Dry Creek, and a similar long distance from the bank of the Maribyrnong River. These distances are too great from which to effect an aboriginal burial (Gill 1953*d*).

(*d*) The amount of mineralization of bones in the Keilor Terrace varies considerably, but the Keilor Skull exhibits the maximum amount found at that site. Two to over four millimetres of encrustation is found both inside and outside the skull, although this has now been chipped from most of the exterior surface, a thin layer of calcite can be seen lining small cavities and occupying the fine space between the alveolus and tooth in some instances.

(*e*) In places the Keilor Skull shows evidence of abrasion. For example, the left zygomatic arch was broken before mineralization (see photo of uncleaned skull, these Memoirs 13, plate I., fig. 2, and compare plate IV., fig. 2), and the posterior end of it is rounded and smoothed. This and other similar abrasion shows that the skull was a piece of sedimentary material before final burial—a natural and not a manmade interment. The small degree of abrasion, however, shows that the skull was not moved far.

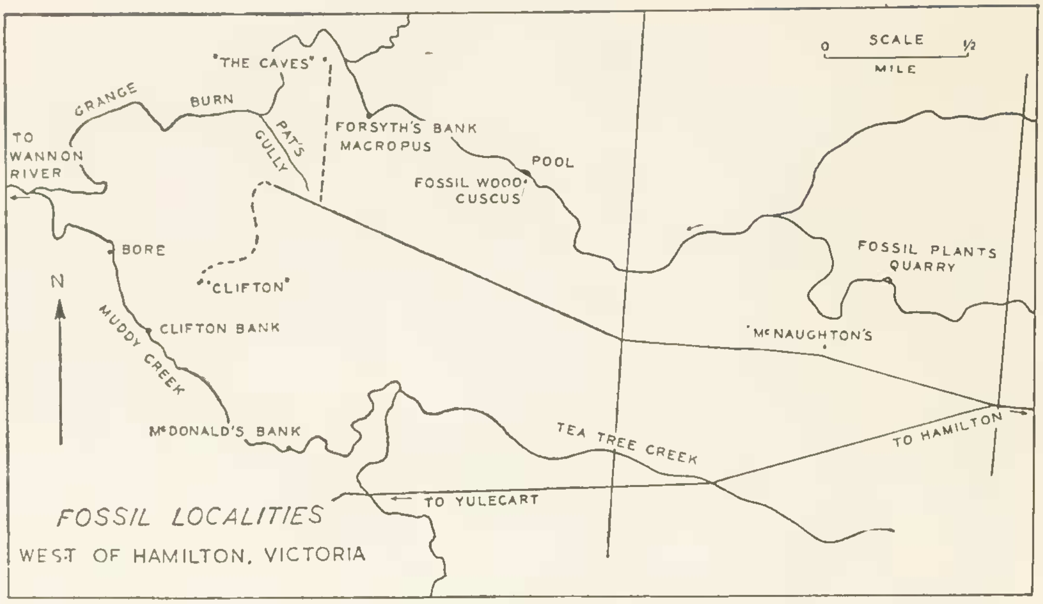
(*f*) Just above where the Keilor Skull came from in the terrace is an important diastem or minor disconformity. The " sinuous band of greyish-red sand, about 2 inches thick, in which are thin layers of calcined bones, ashes, and fragments of red ochre " referred to by Keble (1946*b*, Keble and Macpherson 1946) appear to have been associated with this sedimentational break. Even if the skull were a burial, the above materials and the quartzite flake extracted from them by Professor E. S. Hills (Mahony 1943*b*, Keble and Macpherson 1946) are good evidence of human occupation. According to the memories and notes of those who first saw the excavation, the skull was not found in contact with the layer of ash, &c., but a few feet from it.

The discovery of the skull happened in war time, and investigations that normally would have been made could not be carried out. However, it can now be taken as established that *there was only one Keilor Skull, and that its age is that of the river terrace in which it was discovered.*

Tertiary Marsupials

GROUP E is a suite of three specimens analyzed to test the validity of a Tertiary marsupial fossil, which is the only published record of an Australian Tertiary marsupial apart from *Wynyardia bassiana* from the marine bed at Fossil Bluff, between the town of Wynyard and Table Cape on the north coast of Tasmania. The Tertiary deposit at Fossil Bluff rests on a platform of Permian tillite, the surface of which is only a few feet above low tide level. At the base of the Tertiary sediments is a calcareous conglomerate consisting of many kinds of rocks derived from the tillite, plus small quartz pebbles and sand, plus a large number of Tertiary shells, mostly fragmentary (the *Crassatella* Bed of Johnston 1876, who recorded fossil wood therefrom). This grades into a highly fossiliferous yellow clayey limestone (the *Turritella* Bed). In the higher part of the cliff the marine fossils almost disappear, and near the top some leaves of land plants have been found along with a few broken and worn shells. In the National Museum is a piece of fossil resin (P. 15778) from this cliff, obtained from R. M. Atkinson in 1911. The Fossil Bluff is capped with basalt, and the sea constantly attacks the cliff, keeping the base clear. *Wynyardia* was found in the *Turritella* bed. There is no diastem in the Tertiary succession at Fossil Bluff, and the beds are considered to all belong to the one phase of sedimentation. The conglomerate at the base suggests rejuvenation and submergence, while the reduction of marine fossils and the appearance of leaves of land plants at the top (although the bed is still marine or estuarine) suggests emergence. The general facies is near-shore, and the presence of *Wynyardia*, wood, resin, and leaves suggests the proximity of a river down which these were washed. *Wynyardia* is a possum quite like *Tricohosurus* (Wood Jones 1930), so much so that some have wondered why a new genus and family were erected to accommodate the species. It has generally been agreed that the age of the Fossil Bluff beds is Janjukian, which Singleton (1941) regarded as Upper Oligocene to Lower Miocene, but Raggatt and Crespin (1952) now consider to be Upper Eocene. *Wynyardia bassiana* is therefore a middle or lower Tertiary possum, probably washed down a river and interred in near-shore marine deposits.

A somewhat similar history seems to belong to an upper Tertiary kangaroo, a fragment of which has been found in a marine bed exposed on the Grange Burn near Hamilton, Western Victoria. The section is a well-known one called Forsyth's Bank (Chapman 1914, Singleton 1941). See text-figure 1. At the foot of the bank is a shell bed of Lower Pliocene



TEXT FIGURE 1.

age, and from it Mr. A. C. Frostick and Mr. F. S. Colliver collected part of a mandibular ramus (Plate 1, figs. 5-8), which has been recorded by Colliver (1933) thus:—

> "The most interesting specimen was collected by Mr. Frostick, and is portion of the right ramus of a wallaby (*Halmaturus?*). This is approximately 2 inches long and contains one perfect molar tooth. It was obtained *in situ* in the midst of the shell bed, and about 2 feet from the surface of the deposit." (P. 71.)

This fossil was given to the Department of Geology, University of Melbourne (reg. No. 2019), and through the kindness of Professor E. S. Hills, the writer has been able to study it, and carry out a fluorine test on it. Doubts have been expressed, although not published, on the validity of this fossil, because it came from a marine bed, and one of Tertiary age. The writer has checked the circumstances of its collection, and there is no doubt that it was collected from the compact shell bed at the foot of Forsyth's Bank. Both the above-mentioned gentlemen saw the fossil in place, and one watched the other remove it. The fluorine test now confirms their evidence.

Some matrix was removed from this fossil before it was photographed. It came mostly from the tooth cavity (Plate 1, fig. 6), but also from around the base of the preserved tooth. This matrix was noted to be the same type of material as constitutes the Forsyth's Bank shell bed. The foraminifera from the matrix were kindly examined by Mr. A. C. Collins, who reports that

Elphidium pseudonodosum Cushman is included (Slide P. 15756). This species was described by Cushman from material collected by Parr from Forsyth's Bank, i.e., the same locality as the fossil kangaroo. Parr (1939, p. 69) says that this species " has not been found elsewhere than in the Kalimnan of the Hamilton District." The common Kalimnan foram *Elphidium imperatrix* (Brady) is probably also present.

The history of this macropodid jaw, its matrix, the attached foraminifera, and the fluorine analyses all join to dispel any doubts about its origin. It is of the same age as the Forsyth's Bank shell bed, i.e., Kalimnan, Lower Pliocene.

Specimen 26 (P. 15767) is a rounded and polished piece of bone, probably whalebone, dug by the writer from the nodule bed which underlies the above-mentioned shell bed. It was obtained from the upstream edge of the pool at the foot of Forsyth's Bank, i.e., about a chain from the site of specimens 24 and 25. The nodule bed used to outcrop at the foot of Forsyth's Bank, but the 1946 flood deposited débris which partly blocked the stream, placing the outcrop under 2 feet of water. Specimen 26 is remarkable for having 3.2 per cent. fluorine, and a fluorine index of 10.8.

Specimen 25 (P. 15768) is a piece of bone, highly mineralized, found after a long search in the shell bed at Forsyth's Bank. The fluorine index of this specimen is near that of the bone from the nodule bed, and invites the thought that it is derived from it. This could easily have happened.

Specimen 24 is the piece of macropodid jaw referred to above. It is a piece of a mandibular ramus of a young kangaroo, preserving the third molar, and is regarded as belonging to the genus *Macropus* in the broad sense. The bone gave a fluorine index of 7.9, which although less than that of specimens 25 and 26, is high enough to prove that it is an ancient fossil, and not a bone recently introduced in some way into the shell bed. If specimens 25 and 26 both originate in the nodule bed, which rests directly on Balcombian clay, then some such difference in the fluorine index is to be anticipated.

The fragment of macropodid ramus which constitutes specimen 24 is highly mineralized, and like the other bones of Group E. contains a good deal of iron, judging by its yellowish-brown colour. In this bone there is one complete tooth, a 3rd molar, anterior to which are the roots of another tooth, and anterior to that again is a tooth root cavity. The molar is 8 mm. wide and 11 mm. long, hypsodont and sharply bilophodont, having two high transverse ridges, 5 mm. apart. There are clearly developed but not very high longitudinal ridges, one connecting the transverse ridges, and one on the small platform ($1\frac{1}{2}$ mm. long) anterior to the more forward transverse ridge. The connecting ridge rises a maximum of about one third of the depth of the low area between the transverse ridges.

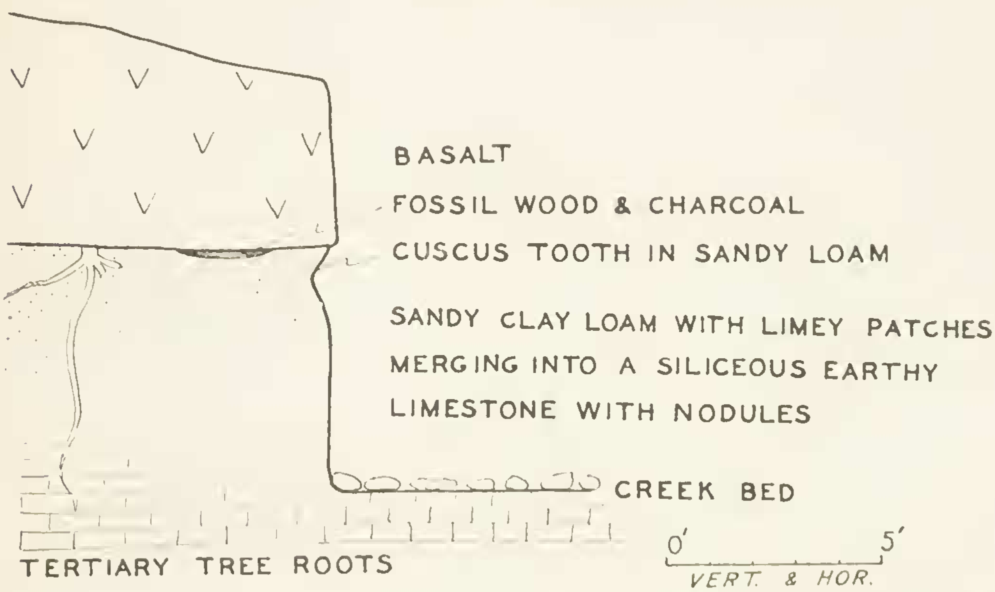
The fossil is clearly of the *Macropus* type, and a young animal. It has the specialized molar pattern of grassland inhabitants. The marine shell bed in which it was found is a nearshore deposit, with the foram *Epistomaria polystomelloides* common in it, and *Amphistegina radiata* in another outcrop of the same bed, indicating warm water conditions (*vide* Parr 1939), but not as tropical as in the preceding Balcombian times. The ecological picture is of a sub-tropical grassland or open forest from which a young kangaroo was swept (probably down a river) into the sea. Its skeleton disintegrated, and all that remains now to our knowledge is the fragment of the lower jaw described above.

Evolution of the Kangaroos

Although of Lower Pliocene age, the Forsyth's Bank kangaroo is a specialized grassland animal. Raven and Gregory (1946) say, " Notwithstanding the great differences between the primitive *Hypsiprymnodon* and such highly specialized genera as *Macropus*, *Dendrolagus*, and *Sthenurus*, the survival in the existing and Pleistocene faunas of so many living fossils, together with the failure of any of the kangaroos to spread from New Guinea into Malaysia, suggests a relatively late geological date (middle to late Tertiary) for the origin of the family from phalangers akin perhaps to the Pleistocene *Burramys*." The kangaroo from Forsyth's Bank proves that the Macropodidae evolved before the late Tertiary. As Australia has been a biological asylum for more than 70,000,000 years with no competition from the newer and more efficient placental mammals, it is not surprising that there are many " living fossils." Spread of the kangaroos from New Guinea to Malaysia could not take place because of the ocean deep effectively separating the two areas over a long period of time.

Tertiary Cuscus

Above the Kalimnan (Lower Pliocene) shell bed with the fossil kangaroo jaw at Forsyth's Bank on the Grange Burn there is a yellow limestone which has been leached so as to remove the aragonitic shells, of which casts and molds survive, but leaving the calcitic ones. The limestone is quite crystalline in places due to redeposition of calcium carbonate, probably a function of a podsolizing process. This bed is a shallow water one, and further upstream it becomes glauconitic, pebbles become common, and strong current bedding is present. Exhumed porphyry rock stacks are also there. The top of this limestone has been weathered into a podsolozed soil, and is now sealed off with a basalt flow which also preserves Tertiary plants in position of growth (Gill 1952). Where the Grange Burn flows off the basalt on to the Tertiary



TEXT-FIG. 2. Occurrence of Pliocene cuscus on the south bank of Grange Burn, near Hamilton, Victoria.

rocks, there is a pool on the south side of which the section shown in text-figure 2 occurs. From the firm and underent fossil soil 6 inches under the basalt a fossil tooth was dug out by the writer. The tooth has now been cleaned, and what there was of the root of the tooth crumbled away with the matrix, leaving only the crown. It can be seen from Plate 1, figs. 1-4 that there are poorly developed transverse and connecting ridges, but the tooth is essentially of the quadricuspid type. It is an upper molar of an adult, and the maximum diameters are 8 mm. by 8.5 mm. Mr. C. W. Brazenor, the Curator of Mammals of the National Museum of Victoria, has kindly studied this tooth (reg. No. P. 15777) with me, and the nearest living animal with which it can be compared is the cuscus. This fits the rain-forest habitat suggested by the accompanying fossil flora which includes *Phyllocladus* and *Araucariacites*. Evidence has been given for regarding this bed as Upper Pliocene in age (Gill 1952). De Vis (1889) recorded a giant fossil cuscus from Queensland Post-Tertiary rocks.

Australian Tertiary Marsupials

The Grange Burn Tertiary beds have thus yielded a Lower Pliocene kangaroo and an Upper Pliocene cuscus. The stratigraphical relationships of the known Australian Tertiary marsupials is given in text-figure 3. It is of interest to note that

Time.		Fossils.	Ecology.
Quaternary.	Holocene.. ..	Fauna similar to the present ..	Varied
	Pleistocene ..	Giant extinct marsupials and forms similar to the present	Varied
Tertiary.	Upper Pliocene ..	cf. Cuscus	Rain forest
	Lower Pliocene ..	cf. *Macropus* (Kangaroo) ..	Grassland or open forest
	Miocene	Forms recently found but not yet reported	
	Oligocene to Eocene	*Wynyardia* (Possum)	Forest

Text Figure 3.

the only three known Australian Tertiary marsupials (the above two and *Wynyardia*) are herbivores (two phalangerids and one macropodid), all are diprotodonts, and all comparable in size with their extant congeners.

Fluorine Distribution

The ranges of fluorine content for the various geological periods concerned are:—

	% Fluorine	Fluorine Index
Extant	0.002–0.10	<0.01– 0.4
Holocene	0.15 –1.70	0.5 – 6.0
Pleistocene	0.30 –1.95	1.5 – 7.9
Tertiary	1.95 –3.20	7.9 –10.8

Both fluorine percentages and fluorine indices have an overall increase with age. The bones whose fluorine content is high for their geological age are those from the Bushfield site and from the Lake Colongulac site. In both cases they are under basaltic tuff containing apatite.

Description of Plate 1.

The fossils were coated with ammonium chloride, then photographed by Mr. L. A. Baillôt of the Melbourne Technical College, to whom I am indebted for his expert assistance. None of the photographs has been retouched.

Fig. 1. cf. *Cuscus* from fossil soil, Grange Burn, Victoria. Pliocene, probably Upper Pliocene, × 4.

Fig. 2. Same as fig. 1, but natural size.

Figs. 3–4. Same tooth, oblique view. Fig. 3 natural size, fig. 4 × 4.

Fig. 6. cf. *Macropus* from marine shell bed, Grange Burn, Victoria. Lower Pliocene. × 4.

Figs. 7–8. Same as fig. 6, but lateral view. Fig. 7 is natural size, while fig. 8 is × 4.

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Plate 1.